Water Meter Reading With Segways: Life Cycle Cost Analysis Report

Prepared by Gibson Economics Inc.

For

City of Seattle
Office of Sustainability & Environment

June 10, 2003

Contact: Kim Drury, OSE 206-684-3214

Table of Contents

Water Meter Reading With Segways:
Life Cycle Cost Analysis Report

I. Introduction

Segways are two-wheeled personal mobility vehicles with internal gyroscopic balancing devices that allow a rider to accelerate, decelerate, and steer by simply leaning. They are battery-powered, and operate at speeds of up to 12 miles per hour. Their combination of size, speed, maneuverability, and load-carrying capability suits them to tasks and uses that require walking, starting and stopping in an urban environment.

The City of Seattle, through the Fleets and Facilities Division (FFD) of its Department of Administrative Services, has researched Segways, and has examined a range of City services to determine which activities might provide an efficient application for Segways.

The City service identified for further testing and evaluation is meter reading, specifically, water use meter reading. FFD, in cooperation with Seattle Public Utilities (SPU), has trained meter readers, and undertaken a pilot study during which participating meter readers have used Segways on their routes. The pilot period lasted from approximately mid-October through mid-December 2002, during which time about 175 daily routes were read by meter readers using Segways for transportation.

The City's Office of Sustainability and Environment (OSE) has joined with FFD and SPU to oversee evaluation of the Meter Reading Pilot Study. OSE promotes the use of evaluation techniques that encompass a full range of costs and other impacts over the lifetime of proposed City investments and programs. The analytical approach favored by OSE to accomplish this is life cycle cost analysis, which in this application identifies and, to the extent practical, quantifies the comparative costs of performing the meter reading function with the aid of Segways versus the current standard approach used by the City.

This report presents a description and analysis of the results of the joint FFD/SPU/OSE Segway Pilot Study. The purpose of the report is to provide a summary of quantifiable and other impacts of Segway use that will aid the City in making a decision concerning wider, permanent deployment of Segways for Water meter reading. The report also contains recommendations concerning: 1) ongoing information gathering that will aid the City in finding the ideal mix of Segway and non-Segway water meter routing over time, and 2) how to translate the results of this study onto other potential City applications of Segways.

II. Potential Segway Application - SPU Water Meter Reading

SPU Water Meter Reading Background. SPU reads water meters throughout the City for both residential and commercial accounts. It does so primarily with one-person routes that include a mix of walking, driving and walking/driving routes. The transportation choice among these route types depends on the distance between meters being read, and to a lesser extent on the topography of the area. Predominantly Commercial routes tend to cover enough area to require a vehicle, and are generally driving routes. Predominantly Residential routes typically cover smaller, contiguous areas, but in some cases they, too, are widely enough dispersed to require a vehicle. When a vehicle is used, it is a City car, provided, serviced and charged for by FFD.

There are about 16 separate routes read each day, Monday through Friday. The Residential routes are on a two-month cycle, so each residential meter is read six times per year. Commercial routes are on a one-month cycle, so they are read twelve times per year. In addition, SPU has a very limited number of weekend meter reading routes, which include special readings of “Can’t Read” meters that were missed on their regular routes, either because the meter reader could not find them within a reasonable time or because the condition of the box made it too difficult to obtain a read. Occasionally, weekend reading of routes is required due to labor shortages during vacations or due to staff illness.

Description of SPU Water Meter Reading Without Segways. SPU meter readers cover about 300-500 meters per route-day, depending on the nature of the route area. For walking routes, they typically drive to a site where they can park their own car and begin their route. From that point on, their route involves walking between consecutive meters, stopping to read the meter, and recording use information at each meter on their electric I-Tron devices, often while walking to the next meter. The process is repeated until it is time for a break or the reader reaches the end of the route.

In addition to the basic walk-read-record sequence, the meter readers occasionally require some time for searching to locate hard-to-find meters, or for clean-out activity associated with meter boxes that have filled partially with water or dirt. In these latter cases, the meter readers use tools they carry in their fanny packs or tool vests to perform the clean-out.

From an economic perspective, the cost of meter-reading labor involves the sum of 1) read/record time, 2) inter-meter walk time, 3) special service time for search or clean-outs, and 4) special read time for meters that were “Can’t Reads” on their regular route. Labor cost savings in the meter reading function could result from a systematic reduction in any of these key activities. The extent of labor cost savings depends on the amount of time originally required for the activity, and the reduction made possible by changed procedures.

Introduction of Segways represents a changed procedure that may produce savings in the time required for one or more of these basic activities.

Water Meter Reading Using Segways. Meter readers using Segways transport the Segway (or have it transported) to their route start point. From there, assuming that the route’s meter set is unchanged, the reader travels from meter to meter quickly, taking advantage of the Segway’s speed. Then, after parking the Segway at each meter, the reader reads the meter just as in the current standard arrangement, and records the result before remounting the Segway to go to the next meter.

If there is dirt or water in the meter box, cleaning or bailing is still required, but the reader has access to a larger set of tools than in standard reading, because the Segway allows a reader to carry more than can be carried comfortably on their person by a walking reader.

The sequence of reads may change with Segways. In many walking routes, readers zig-zag up a block, reading meters on both sides of the street. Such crossings are not appropriate with a Segway, and readers will likely travel up one side of the street at a time, staying on the sidewalk, before crossing the street at an intersection to read the meters on the other side.

When Segways replace driving routes, the use of cars or pickups with numerous parks, reads restarts and short drives is replaced by more continuous travel on sidewalks.

In summary, the necessary steps of reading, recording, and travel between meters is generally the same with Segways, but readers carry less equipment on their bodies and more on the Segway, and they ride between meters.

Support activities required with Segways. Meter reading with Segways requires vehicle support activities different from those used in the current standard procedures. First, SPU and FFD must choose one of several strategies for delivering Segways to routes. This may involve providing customized racks for readers to haul their Segway to and from the route. Alternatively, SPU/FFD may use a dedicated vehicle to deliver multiple Segways to route start points for several readers per trip, and again to pick up the Segways at the end of the route.

III. Segway Meter Reading Benefits

Reduced Cost of Meter Reading Travel Time. The primary economic benefit from using Segways for water meter reading will result from reduced travel time between meters. This allows for more meters per route, and thus fewer total routes, which means reduced labor costs.

The extent of such benefits will depend on the current nature of routes converted to Segways, the reduction in travel time that can be counted on for various types of routes, and the practical rerouting opportunities this offers to SPU. The ongoing pilot test of Segways is intended in part to provide the answers to these crucial questions.

In addition to the available efficiency savings from Segway use, it is important to account for the time it takes for a reader to achieve those savings, as he/she becomes familiar with Segways and with their use on individual routes.

Section V below develops the estimates for both the potential efficiency savings and the "ramp-up" to those savings that are incorporated in the life cycle cost analysis.

Reduced Cost of Special Return Read Trips for "Can't Reads". Meters that can't be read occur on most routes. They require estimated usage for billing, and if repeated for the same meter, they can require special route trips on weekends. Any operational change that reduces Can't Reads will improve the accuracy of billing, reduce customer service questions and complaints, and potentially reduce the need for special route assignments.

Segway routes provide meter readers with improved resources to reduce Can't Reads. Meter readers carry more tools with Segways, and don't carry them on their bodies. The greater availability of tools and reduced reader fatigue may allow readers to achieve reads on more problem meters than they have in the past.

The most significant benefit of reduced Can't Reads will occur if SPU is able to reduce weekend special look-up routes. These routes require additional labor, and typically employ the most costly senior staff as well, at premium (overtime) pay. The baseline analysis below conservatively assumes that 4 hours of reduced look-up time per year per route string will be realized from improvements in Can't Reads.

The ongoing pilot test of Segways is also intended in part to determine whether this advantage translates into reduced Can't Reads. Can't Reads are listed on each daily route report, and any change in their relative frequency with Segways will be easy to identify.

Reduced Worker Injury Cost. The City self-insures for the occasional costs associated with Meter Reader injuries. Averaged over several years, these costs are not large. Nevertheless, the reduced physical strain on Segway routes, both from smaller weight-carrying requirements and reduced walking effort may translate into some reduced City costs for medical care, and possibly even more significant reduced costs due to reductions in temporary replacement staff that are required to cover for injured Meter Readers.

The average annual injury cost per reader per year over the period 1998-2002 was $988. In the lifecycle cost analysis below, it is assumed that Segway use produces a savings of 20% in injury costs, either through reduced frequency or reduced severity.

Reduced FFD Drive Route Costs. While there are similar route time savings for each type of route, there is an added advantage for adopting Segways on Drive and Drive/Walk routes. For those types of routes there is a benefit from reduced fleet costs associated with reducing the current reliance on City vehicles. It is difficult to link specific vehicle use and cost information to this function. For the analysis below, it is assumed that SPU meter reading vehicle costs will decline by an average of $400 per route.

Potential Election to Expand to Monthly Meter Reading. The labor efficiency gain described above assumes that SPU Water Meter Reading would continue to be performed on a bimonthly basis for most customers. While this efficiency benefit is consistent with current meter reading policies, Segway route savings would also provide SPU with a lower-cost option to expand all meter reading to monthly cycles.

Since the benefits of doing so will be unchanged while the costs will be reduced, SPU could elect to realize those benefits, which include improved customer service, quicker identification of leaks, improved water use data for program planning, more accurate rate base tracking and billing, and other benefits to SPU. These benefits are not readily quantifiable, but if they may be deemed sufficient to justify a switch to monthly meter reading, given the lower cost of Segway meter reading.

Reduced Consumption of Fossil Fuels. Meter Reading requires fuel use, with or without the use of Segways. Routes performed with Segways require electricity to charge the Segway batteries, as well as increased round-trips from routes to the shop, to drop off Segways at the end of each route day. On the other hand, Segway routes that replace Drive or Walk/Drive routes eliminate the fuel consumption of dedicated vehicles on such routes.

The fossil fuel use and carbon budget impact of vehicles used in either Drive or Drive/Walk routes is expected to exceed the fossil fuel used in producing the electricity for Segway use and in driving any support vehicles for Segway routes.

In addition to the economic savings of this net fuel economy, there will also be ongoing carbon budget savings and air quality impacts associated with the change.

IV. Segway Meter Reading Costs

Segway Vehicle Purchase. Initial vehicle cost for Segways includes a fully operational vehicle with wheels, two sets of batteries and other standard operational features. FFD has acquired ten Segways for use in the pilot study, and in the process has negotiated a price for the model and associated equipment options needed for meter reading application. The full cost, including extras and taxes, is $6,743 per Segway.

Life Cycle Cost Analysis requires assumptions about the life of the vehicles, to support a thorough comparison of costs and benefits over a full life cycle. Segway manufacturers estimate the vehicles' life at five years, which assumption has been used in this report. Segways are a new enough product that there is not yetwell-documented information on their average life. Given that uncertainty, potential purchasers such as the City of Seattle should also examine the economic case for Segways at higher and lower projected average life periods.

Segway Internal City Lease Option. SPU could opt either to be the purchaser/owner of Segways, or to lease Segways from FFD, in which case SPU would have a more certain basis for projecting the annual and life cycle costs of the Segway vehicles. SPU continues to explore both lease and purchase options. However, viewed from the City of Seattle's overall perspective, that decision only involves whether SPU or FFD bears the risk associated with uncertainty regarding the average Segway life. The economic outcome for the City as a whole will be the same in either case, and that is the perspective assumed in this report.

Segway Component Replacement. Certain Segway components are expected to be replaced more frequently than the basic vehicle. Including these anticipated periodic replacement purchases is an important component of life cycle cost analysis of Segway meter reading application. The key replacements include new battery packs and wheels, each of which has a projected life in Segway support literature. Wheels are estimated to require replacement at two- and one-half year intervals. Battery replacement cycles are based on use. The battery sets selected by FFD for the SPU meter reading Segways are estimated to last for 400 recharges. With meter reading Segways requiring a recharge every route day, the life cycle for battery sets is approximately one-and-one-half years, based on 260 route-days per year.

Segway Battery Electricity Use. The battery-powered Segways require electricity for daily battery recharges to prepare for the next route day. The actual amount required, however, is quite small. The manufacturer estimates an electricity requirement of 0.2 kwh per charge. An independent researcher has estimated that Segways left connected for recharge for the entire time between uses use a out 0.4 kwh per charge. The latter assumption is used in this report.

The small energy requirement of Segways reflects the limited load they must transport. Unlike drive route automobiles, which weigh about a ton when fully loaded, Segways' weight when underway, including drivers and tools, is approximately 250-300 pounds.

Transport Racks or Support Vehicles. Segways require a conveyance to carry them to and from routes, due to their size and weight. The current logistical candidates for a permanent meter reading application are customized racks, which the meter readers could use with their own vehicles, or a City van, which could carry several Segways at once to initiate several routes.

The customized racks attach to the rear of regular vehicles, using a trailer hitch, and can be used with meter readers' own vehicles, which they currently use to travel to Walk routes.

If a City van is used, it will be capable of carrying 4-5 Segways to separate routes in the same general area, with one meter reader driving the van while the others caravan in their own vehicles to their route drop-off point. The van driver for the day will collect all 4-5 Segways and return them to the SPU Shop, while the remaining meter readers will return home in their own vehicles.

Initial Training in Segway Use. Initial training by FFD staff is necessary to prepare a meter reader to use a Segway adeptly on routes,. The per-route life cycle cost associated with this training includes both allowance for the time of the FFD staff trainer, and the frequency of new meter reader training that will be needed.

Based experience during the ongoing pilot study, FFD estimates that one day of its trainer's time will be required for each new SPU Segway trainee. SPU estimates, based on its meter reader turnover pattern, that it will need to train three new meter readers per year, to maintain adequate trained staff to support a set of ten Segway routes per day.

Re-routing Costs. The Segway economic benefits described above were primarily those associated with more efficient meter reading and the increased route size that efficienty makes possible. To the extent that Segways increase overall route speed, it will be necessary for SPU to re-route its meter reading function, to consolidate routes and thus realize the available efficiencies provided by Segways.

Water meter reading re-routing is a complex and costly process. The SPU re-routing that was completed in 2000 provided SPU with experience in the practical requirements of such an exercise and both the computer and staff support costs that are entailed. SPU experience in re-routing suggests that the cost of another re-routing could be as high as $450,000, to establish a new set of routes that could include ten or more Segway routes per day.

V. Quantification of Route Efficiency Impacts

A. Efficiency Savings: Modeling Approach. The largest single benefit of Segway use in meter reading stems from the time savings on routes. This in turn depends on the nature of meter reader routes' time requirements and the associated potential for time savings. **Table V-1** below shows the approximate composition of a meter reader's average day:

Table V-1: Meter Reading Time Split Among Activities

Activity	Time
Transportation to/from route	1/2 hour
Breaks	1/2 hour
Administrative/miscellaneous	2 hours
Route reading	5 hours

Meter readers make a daily stop at the SPU shop to pick up route materials and report route data. They also are allowed two fifteen-minute breaks per route day. Each of these activity categories requires approximately 1/2 hour.

The Administrative/Miscellaneous category encompasses many different activities, from reviewing e-mails, to attending meetings, to preparing equipment for reading activities, along with paid time off for vacations and illnesses. Since these all represent time unavailable for meter reading, they are combined to derive the average number of hours per day per FTE available for meter reading.

The remaining time - about five hours per day - is comprised of actual on-route activities, which include accessing the meter, reading, recording, and traveling between meters. The most significant potential savings from Segway use for meter reading is expected from the time savings on routes. Travel speed on the route is expected to increase substantially with Segways, thus reducing travel time. **Table V-2** shows a range of expected changes in average travel speed, travel time, and overall route time for walking routes converted to Segway routes. The table is based on a route requiring a total of seven miles of walking.

Table V-2: Percentage Meter Reader Time Savings At Alternative Segway Average Travel Speeds (modeled)

(1) Travel Speed Between Meters	(2) On-Route Travel Time	(3) Total On-Route Time	(4) Savings in Shift Time [1]
Base: 2.5 mph	2.80 hours	5.00 hours	---
Segway: 5 mph	1.40 hours	3.60 hours	-17.5%
Segway: 6 mph	1.17 hours	3.37 hours	-20.3%
Segway: 7 mph	1.00 hours	3.20 hours	-22.5%

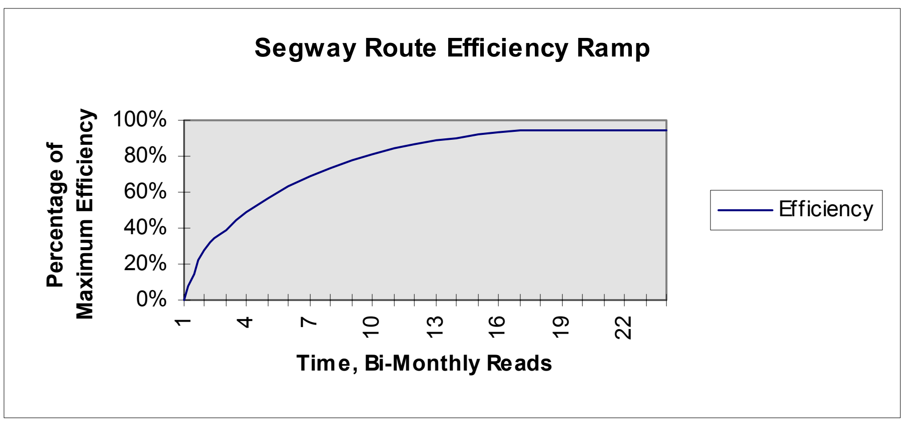
[1] Based on an 8-hour shift, with 300-400 meters

The percentage of meter reader time saved by faster average travel time between meters is shown in Column (4). For the conservative range of Segway average speeds shown, the savings are still substantial.

Typically, there is variation in average walking speed among different meter readers, and the potential for time savings differs accordingly. If a meter reader averages 2.0 mph walking, the time savings from each of the Segway speeds shown will be greater by 8.8%; conversely, if a meter reader averages 3.0 mph walking, the percentage savings shown will be smaller by 5.8%.

Segway Meter Reading Efficiency Ramp. If Segways are adopted permanently for water meter route application, readers will require some period to become familiar with them. As readers become more experienced with Segways, their route performance can be expected to reflect the modeled efficiency outcomes more and more closely. Even when the vehicles have been in use for some time, newly hired readers will require a learning curve to become fully adept at their use.

These two factors taken together suggest that 1) there will be a program ramp-up period affecting all readers when the vehicles are adopted officially, and 2) the maximum efficiency will not reach 100% over time, due to ongoing turnover in the meter reader corps. **Figure V-1** shows the program ramp assumed in this analysis. It is consistent with the pilot program experience described below, and reflects an average 40% of maximum efficiency gain in the first year (six full read cycles), leveling out at 90% of maximum efficiency in the fourth year.



C. Efficiency Savings: Meter Reading Pilot Results. The time savings estimates described above are based on model conditions in which only the average travel speed changes, by a specific amount. As Segways are deployed, there are several types of adjustments required of meter readers. They must become familiar with the Segway, and adept at using it in the most time-efficient manner while preserving battery life. In addition, they may modify the sequence of meter reads for safety or efficiency. They may also devote increased time to reducing "Can't Reads," because of their expanded supply of tools and their preserved stamina.

To field-test the meter reader's route adjustments with Segways, SPU and FFD coordinated and carried out a two-month pilot study of Segway use on 196 water meter reading routes. The pilot study covered one full cycle of routes between October 26 and December 23, 2002. Since that time, SPU has continued to perform a portion of their routes with Segways. Results from the pilot periods before and after December 23 provide an opportunity to examine the extent of certain route changes as well as how much they "ramp up" over time.

"First Round" impacts described below refer to the route performance statistics and notes from the first complete Segway cycle. In that period, meter readers were doing each route for the first time with a Segway, and in some instances doing the route itself for the first time.

"Second Round" impacts refer to the performance statistics and notes from the second cycle of Segway use, specifically to instances where a reader had the opportunity to use a Segway on the same route for a second time.

In the First Round, the meter readers were in a situation somewhat like training routes. The read sequence with a Segway was frequently modified from the sequence meter readers used when walking. This had the expected effect of limiting the realization of time efficiencies.

On the other hand, the readers performance showed an immediate First Round advantage in dealing with difficult-to-read meters, presumably due to the availability of the greater number of tools carried by the Segway, and their own freshness from not having to carry heavy tools while walking.

Table V-3 and **Figure V-2** show the relative route times for Segway and non-Segway routes during the 41 days of the Pilot Study's first Round. To normalize for differences among readers, the comparative data is based on Segway and non-Segway routes that were performed by the same reader in the First Round of the Pilot period and in the immediately preceding cycle. This reduced the Segway sample to 47 routes.

There was considerable in results variability, as might be expected from different readers making their first efforts with the Segways on a wide variety of routes, some of which were familiar to the readers, and some of which were not.

Overall, the time impact was approximately neutral. Weighting the non-Segway results for individual days in the same proportions as Segway routes per day - to normalize for weather variability - the Segway routes had an average route time **decrease of 2.30 minutes**, while non-Segway routes had an average route time **increase of 0.39 minutes**.

Either of these Segway averages represents a considerably better result than normally found in training routes for current walking routes, where times 1-3 hours above normal are not uncommon.

Table V-3:
First Round Route Time Differential

Route Group	Sample Size	Change	% Faster	% Slower
Non-Segway	34	+0.39 min	53%	47%
All Segway	47	-2.30 min	51%	49%
Drive	5	+5.60 min	20%	80%
Drive/Walk	4	+25.25 min	50%	50%
Walk	38	-6.23 min	55%	45%

Figure V-2 shows the route time impact pattern over the 41 days of Round 1. It is reasonable to expect that while readers may require several cycles to achieve the efficiencies possible on individual routes, they may show some relative improvements in their first-time performances route-by-route as they become more familiar with the Segway itself.

The rolling average charted in **Figure V-2** shows that there is a modest, but noticeable, reduction in comparative Segway times over the course of the First Round of the Pilot period. The pattern is obscured somewhat by one very large descrease and one very large increase in time among the sample routes.

Figure V-2:
Change in Route Time with Segways, Round 1

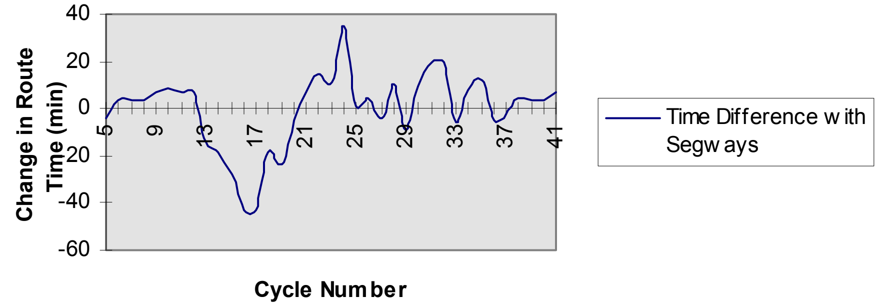


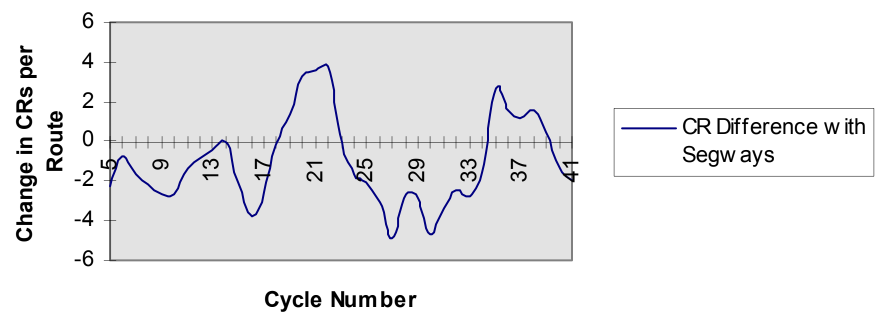
Table V-4 and **Figure V-3** show the relative incidences of "Can't Reads" on Segway and non-Segway routes during the 41 days of the Pilot Study's First Round. For both Segway and non-Segway routes, the impact measure is number of Can't Reads versus the corresponding number for the same route in the previous read cycle. As noted above, this helps to eliminate reader differences, weather-related differences, and potential route-selection bias between Segway and non-Segway routes.

Table V-4:
First Round Can't Read Frequency Differential

Route Group	Sample Size	Change	% Reduced	% Increased
Non-Segway	34	+0.76 CR		
All Segway	47	+0.17 CR	34%	36%
Drive	5	+1.80 CR	40%	40%
Drive/Walk	4	-3.50 CR	100%	0%
Walk	38	+0.34 CR	26%	39%

The 47 Segway routes with consecutive cycles by the same reader showed an average increase of 0.17 Can't Reads during the First Round period. This represents very little change, but compares quite favorably with the average increase of 0.76 Can't Reads for non-Segway routes performed by the same readers in consecutive cycles in the same period.

Figure V-3:
Change in Can't Reads with Segways, Round 1



The Can't Read impacts are shown graphically in **Figure V-3**. Despite substantial variation, there is an evident improvement from the beginning of the pilot period, and an average reduction of over 0.5 Can't Reads per route for the entire period.

In the Second Round, readers were able to realize more of the savings that normally occur as a route becomes familiar, together with the efficiency gains from more rapid on-route travel with the Segway. Based on the available sample of 22 Second Round routes on which the same reader was using a Segway for the second time, the route time savings were very significant, as shown in **Table V-5** below.

Table V-5:
Second Round Route Time Differential

Route Group	Sample Size	Change	% Faster	% Slower
Non-Segway	61	+4.16 min	51%	46%
All Segway	22	-24.64 min	82%	18%
Drive	5	-25.60 min	80%	20%
Drive/Walk	2	-54.00 min	100%	0%
Walk	15	-20.40 min	80%	20%

Segway routes being read for the second time by the same reader were completed in 24.64 minutes less time, on average, than they had been in their previous round. The weighted average route time difference for non-Segway routes performed by the same reader for the second consecutive time in the same period of days was an increase of 4.16 minutes. Overall, the average time savings for Segway routes in the Second Round reads was nearly half an hour 28.8 minutes) per route. This is approximately one-third of the modeled savings projected for mature route operation with Segways, and is consistent with the “ramp up” period associated with introduction of new programs or procedures, particularly when repetitive time and motion behaviors are involved.

The average time savings are different for Drive, Drive/Walk and Walking routes. While the samples of Drive and Drive/Walk routes performed with Segways was small (5 and 4, respectively in the First Round), each showed a time increase, while there was a time decrease for Walking routes done with Segways. This may reflect the greater complexity of the procedure adjustments involved in changing from a mixed travel pattern to a Segway pattern.

In the Second Round, the average time savings for Drive routes exceeded that for Walking routes, producing roughly the same composite time savings relative to the pre-Segway baseline period for routes that had had each of those baseline travel modes. The Second Round savings for Drive/Walk routes was even greater, but not reliably so, since it was based on a sample of only 2.

Net Quantified Economic Impacts. Table V-6 summarizes the economic benefits and costs of Segway application to meter reading over the 10-year life cycle of the vehicles. Under the baseline assumptions described in Sections III, IV and V above, the Benefit:Cost ratio over a ten-year projected program/vehicle life is **1.42**, based on benefits of $88,854 per route and costs of $62,614.

As indicated in Table V-6, efficiency gains account for a large majority of the projected life cycle benefits. Re-routing costs, on the other hand, account for the majority of projected life cycle costs, exceeding the Segway vehicle and replacement costs by a considerable margin.

The projected Benefit:Cost ratio exceeds the break-even threshold of 1.0. Two additional factors, however, are important to overall program review and decision-making. One is the set of non-quantified benefits and costs associated with this Segway application. These were instrumental in the City’s original examination of Segways for City use, and are described in the paragraphs below.

The other important factor is the uncertainty surrounding the projected benefits and costs. As with many new technologies and procedures, it will take further experience to determine more precisely the actual economic benefits and costs of Segway use. Nevertheless, it is possible to explore the stability of the economic results for a range of reasonable alternative assumptions. This is the subject of Section VI below.

Non-Quantitative Benefits and Costs. Net environmental impacts are a significant consideration in many decisions that involve a changs in procedures. In the case of Segway deployment for meter reading, the principal environmental change involves the use of fossil fuels. While estimated energy use and costs for the Segway and non-Segway alternatives are reflected in Table V-6, there will also be vehicle emission impacts not fully accounted for in the direct economic calculations.

For Drive and Drive/Walk routes as currently constituted, meter readers travel the route distance with vehicles, and also leave vehicles idling for a significant period. Each of these vehicle uses contributes to air pollution in the Seattle area. Segway use on any of these Drive or Drive/Walk routes reduces fossil fuel use and vehicle emissions, replacing them with consumption of just 0.4 kwh of electricity per day. Other vehicle uses, such as driving to the shop at the beginning of each day and driving to the route start point, remain essentially the same as before, producing no net change in air emissions.

On balance, the environmental impacts of Segway use for water meter reading are expected to be positive.

A second set of non-quantified impacts involve the change in physical difficulty of meter reading. Current walking routes are tiring, whether or not they produce injuries for meter readers. Segway routes are physically less taxing, as noted frequently in the readers' daily comment sheets during the pilot period. This reflects a benefit, even though it is difficult to measure and quantify for an Benefit:Cost calculation. One reader commented on the reduction in exercise from using Segways, which may be balanced by increased remaining energy for recreational activities.

VI. Sensitivity Analyses

A. Cost Sensitivity Cases

1. Segway Vehicle Life. The baseline analysis assumes that FFD purchases Segways, and that they have a five-year life for the basic vehicle. If the actual life of the vehicles is longer, the net economic benefits will be greater, and conversely, a shorter life will reduce the net benefits. Two alternative cases, and their Benefit:Cost ratios, are summarized below.

Table VI-1: Impact of Alternative Segway Vehicle Lives on Meter Reading Benefit:Cost Ratio

S/A Case	Assumption	B:C Ratio
Alternative A	3-year vehicle life	1.33
Alternative B	7-year vehicle life	1.50

2. Segway Cost Escalation Over Time. The baseline analysis employs a 10-year life cycle. This allows for the various benefits and costs to be compared directly, since some are repeated annually, some at 2-1/2 year intervals, and some at 10-year intervals. The 10-year period involves two assumed life cycles for the Segway vehicles.

In the baseline, the second round of Segways is assumed to cost 3% more each year, in inflation-adjusted dollars, than the first round of Segways. Newly introduced vehicles and other products, however, occasionally depart from that model. The two alternative scenarios evaluated and summarized in Table VI-2 assume that the price 1) increases by 5% more than inflation, or 2) conversely, remains constant relative to inflation.

Table VI-2:
Impact of Alternative Segway Cost Escalation on Meter Reading Benefit:Cost Ratio

S/A Case	Assumption	B:C Ratio
Alternative A	5%/year deflation	1.47
Alternative B	0%/year inflation	1.37

3. Segway Battery Life. The baseline analysis assumes, based on the manufacturer's estimate, that the Segway battery packs selected by FFD will remain in use for 400 charges. To determine the sensitivity of the results with respect to that assumption, the two cases summarized in Table VI-3 assume batteries remain in use for either 300 or 500 charges.

Table VI-3:
Impact of Alternative Segway Battery Lives on Meter Reading Benefit:Cost Ratio

S/A Case	Assumption	B:C Ratio
Alternative A	500 Charges/battery	1.45
Alternative B	300 Charges/battery	1.39

4. SPU Re-Routing Costs. The cost of a meter reading route reconfiguration study is the single largest component of the cost of adopting Segways for water meter reading. The baseline cost estimate is $450,000, based on SPU experience with its 1999-2000 rerouting effort. That cost consists of a combination of staff time assigned to the labor-intensive analysis in such a study, together with contract and software costs of a study.

It is possible that the actual cost could be substantially higher or lower. The cost of the previous study was over $600,000, although there were several activities that SPU learned were not particularly efficient, and which it will expect to avoid in its next rerouting. Conversely, by eliminating unnecessary activities and performing others more effectively based on its fairly recent experience, SPU could also complete a reroute for as little as $300,000.

Note that the baseline assumes that only ten routes will be converted to Segway reading. SPU is considering increasing that number, which would also lower the per route cost of meter reading proportionally.

Two alternative rerouting cost cases were considered, and their respective impacts on the Segway Benefit:Cost ratio were calculated:

Table VI-4:
Impact of Alternative SPU Re-Routing Scenarios on Meter Reading Benefit:Cost Ratio

S/A Case	Assumption	B:C Ratio
Alternative A	$300,000 study cost	1.89
Alternative B	$600,000 study cost	1.13

In addition, since its introduction of route strings in the past few pre-Segway years, SPU has lowered average route times below the five hour design standard. Based on that, SPU may soon need a re-routing study even in the absence of Segway routes. This suggests that

Segway re-routing may be able to capitalize on effort already planned, and that the cost share attributable to Segways will be even less for SPU.

While that may be the case, the baseline cost estimates and sensitivity analyses assume that a new study will be needed. It should be recognized, however, that SPU faces an unusual opportunity to consolidate both efficiency gains, and do so while incurring the cost of only one major re-routing study. If that opportunity were accounted for, the net economic benefit of Segway introduction for water meter reading in Seattle would be significantly larger than estimated above.

5. Customized Rack Cost. FFD has designed customized racks to fit on automobiles, attached with trailer hitches. The projected cost of outfitting a vehicle with both a trailer hitch and a rack is assumed to be $525, which is reflected in the baseline analysis.

It is unlikely that the cost could be much lower than that, since the materials and work involved are well defined. However, the racks could last longer than the five years assumed in the baseline. In terms of annual costs, assuming a seven year life is approximately equivalent to assuming a cost of $375 with the same five-year life, and that is one of the scenarios examined and summarized below.

The other scenario considered assumes a cost of $1,000 with the same five-year life, which might be possible as a result of some combination of shorter rack life or increased vehicle insurance costs if the racks are used regularly.

Table VI-5:
Impact of Alternative Segway Conveyance Costs on Meter Reading Benefit:Cost Ratio

S/A Case	Assumption	B:C Ratio
Alternative A	$375 per Rack	1.44
Alternative B	$1,000 per Rack	1.38

B. Benefit Sensitivity Cases

6. Program ramp-up speed. The baseline analysis assumes that the route time benefits will ramp in over a four-year period, topping out at 90% of the theoretical maximum. If either a smaller fraction of the benefits are realized, or the efficiencies ramp in over a longer time, the benefits will be reduced. Two alternative cases were considered, and their respective Benefit:Cost ratios calculated:

Table VI-6:
Impact of Alternative Segway Program Ramp-Up on Meter Reading Benefit:Cost Ratio

S/A Case	Assumption	B:C Ratio
Alternative A	75% maximum	1.10
Alternative B	6-year ramp	1.35

7. Stop Versus Travel Time Split. SPU water meter routes have varying lengths and numbers of meters, with all combinations intended to require approximately the same amount of time to complete. Due to the range, the fractions of route time associated with travel between meters versus reading and recording also vary. This affects the scope of potential efficiency improvements from Segway use, since the routes with higher fractions of travel time afford SPU greater potential efficiency gains.

The baseline assumes that 46.7% of route time is dedicated to travel between stops. Two alternatives to the baseline case were considered, and their respective impacts on the Segway Benefit:Cost ratio were calculated:

Table VI-7:
Impact of Alternative Route Stop/Travel Time Split on Meter Reading Benefit:Cost Ratio

S/A Case	Assumption	B:C Ratio
Alternative A	40% travel time	1.22
Alternative B	53.3% travel time	1.63

8. Travel Time Reduction/Average Travel Speed Increase. Efficiency gains from Segways are proportional to their reduction in travel time, which depends on the average speed meter readers are able to maintain using the Segways. This speed varies from reader to reader, and from route to route.

Based on the monitoring and observations of FFD staff, the baseline assumes that meter readers travel an average of 6 mph between meters on their Segways. Two alternative cases were considered, and their respective impacts on Segway Benefit:Cost ratio were calculated:

Table VI-8:
Impact of Alternative Segway Average Operating Speed on Meter Reading Benefit:Cost Ratio

S/A Case	Assumption	B:C Ratio
Alternative A	5 mph average speed	1.22
Alternative B	7 mph average speed	1.57

9. Alternative Self-Insurance Injury Cost Savings. The baseline analysis assumes a modest savings in meter reader injury costs will result from the lesser physical burden of reading meters with the aid of Segways. It is very difficult to predict with any precision how great any impact will be. Consequently, this sensitivity analysis examines plausible better and worse cases, to determine the importance of this factor.

The most significant worker time loss cases of the past several years have resulted from back or exertion injuries. At one extreme, it could be assumed that such injuries will be reduced by 50%, producing more than double the per route savings assumed in the baseline case.

At the other extreme, it could be assumed that such costs will not be reduced at all. This scenario might be rationalized as a result of the offset of poorer physical conditioning among readers, as they reduce the daily exercise associated with walking on their routes.

These two alternative cases were considered, and their respective impacts on the overall Segway Benefit:Cost ratio calculated.

Table VI-9:
Impact of Alternative Segway Vehicle Lives on Meter Reading Benefit:Cost Ratio

S/A Case	Assumption	B:C Ratio
Alternative A	50% Injury Savings	1.44
Alternative B	0% Injury Savings	1.40

VII. Conclusions, Recommendations, Next Steps

Life cycle cost analysis of the City of Seattle's introduction of Segways for SPU water meter reading indicates that the economic benefits of their use exceed the economic costs. The economic benefit derives primarily from improvements in route efficiency, which can allow SPU to accomplish the same meter reading with reduced labor costs. The economic costs are comprised primarily of the re-routing study that will be needed to achieve the route efficiencies, and secondarily of the costs of the Segways and their projected replacements and maintenance.

SPU is already in a position where a re-routing may be cost effective, even without deployment of Segways. Consequently, it has a unique opportunity to consolidate the benefits of Segway routing with other efficiencies it has achieved over the past three years, while undertaking only one re-routing study.

A series of sensitivity analyses explored the dependence of the net economic benefit on a variety of alternative assumptions and scenarios. The cases examined determined that there will be a net economic benefit for a very wide set of assumptions, including conservative assumptions about efficiency gains and levels of the primary cost elements.

In addition to the quantified economic impacts of Segway use for water meter reading, the environmental impacts and non-quantified worker impacts are also projected to be positive. Segways will replace a portion of the SPU use of motor vehicles for route performance, leading to reductions in vehicle air emissions. Meter readers using Segways will walk fewer miles, and carry less weight on their bodies while performing their basic tasks.

Looking ahead, any ongoing use of Segways for meter reading should be accompanied by continued data gathering, particularly concerning route time impacts. Early results have shown fairly rapid achievement of efficiency gains. In order to maximize the economic benefits of those gains, however, SPU should monitor how quickly the gains continue to ramp up, to better inform its subsequent re-routing study effort.

Finally, the information assembled in the OSE/FFD/SPU study provides useful indications of the nature of task efficiencies, environmental improvements and worker impacts that may be transferrable to other City functions. The City list of services includes several other basic functions that involve routed staff assignments, some also requiring vehicles and some requiring lifting or carrying heavy items. Any of these activities involves clear parallels to the SPU water meter reading function, and may present additional opportunities for economic and environmental gains through the use of Segways.

Table V6-A

I. Benefits

Assumptions:

	Current	Segway	
Speed:	**2.5**	**6**	MPH
Route Dist:	**7**	7	Miles
Total Time:	8.0	6.37	Hours
Admin:	2.0	2.0	Hours
Stops:	3.2	3.2	Hours
Walk/Ride:	2.8	1.17	Hours

20.4%

Year	Maximum	Ramp (*Efficiency Savings*)	Achieved	Reduced Cust Svc	Reduced Injuries	FFD Savings	Total Benefits
1	$11,778	39%	$4,629	$111	$198	$0	$4,937
2	$11,778	79%	$9,246	$111	$198	$0	$9,554
3	$11,778	85%	$10,012	$111	$198	$0	$10,320
4	$11,778	90%	$10,600	$111	$198	$0	$10,909
5	$11,778	90%	$10,600	$111	$198	$0	$10,909
6	$11,778	90%	$10,600	$111	$198	$0	$10,909
7	$11,778	90%	$10,600	$111	$198	$0	$10,909
8	$11,778	90%	$10,600	$111	$198	$0	$10,909
9	$11,778	90%	$10,600	$111	$198	$0	$10,909
10	$11,778	90%	$10,600	$111	$198	$0	$10,909
						NPV:	**$76,811**

II. Costs

Assumptions:

Charges:	**400**	per set
Batteries:	**$580**	per set
FTE Cost:	**$57,690**	per year
Elec price:	**$0.06**	per kwh
Elec use:	**0.2**	kwh/charge
Support:	**6%**	FTE
Discount:	**5%**	per year

Year	Machine	Batteries	Wheels	Electricity	Rack	Train/Reroute	Total
1	$6,743	$363	$0	$3	$525	$37,633	$45,267
2	$0	$363	$0	$3	$0	$133	$499
3	$0	$363	$190	$3	$0	$133	$689
4	$0	$363	$0	$3	$0	$133	$499
5	$0	$363	$190	$3	$0	$133	$689
6	$7,817	$363	$0	$3	$525	$133	$8,841
7	$0	$363	$0	$3	$0	$133	$499
8	$0	$363	$190	$3	$0	$133	$689
9	$0	$363	$0	$3	$0	$133	$499
10	$0	$363	$190	$3	$0	$133	$689
						NPV:	**$53,270**
						B:C Ratio:	**1.44**

Table V-6B

I. Benefits

Assumptions:

	Current	Segway	
Speed:	**2.5**	**6**	MPH
Route Dist:	**7**	7	Miles
Total Time:	8.0	6.37	Hours
Admin:	2.0	2.0	Hours
Stops:	3.2	3.2	Hours
Walk/Ride:	2.8	1.17	Hours

20.4%

Year	Maximum	Ramp	Achieved	Reduced Cust Svc	Reduced Injuries	FFD Savings	Total Benefits
	Efficiency Savings						
1	$11,778	39%	$4,629	$111	$198	$5,187	$10,124
2	$11,778	79%	$9,246	$111	$198	$5,187	$14,741
3	$11,778	85%	$10,012	$111	$198	$5,187	$15,507
4	$11,778	90%	$10,600	$111	$198	$5,187	$16,096
5	$11,778	90%	$10,600	$111	$198	$5,187	$16,096
6	$11,778	90%	$10,600	$111	$198	$5,187	$16,096
7	$11,778	90%	$10,600	$111	$198	$5,187	$16,096
8	$11,778	90%	$10,600	$111	$198	$5,187	$16,096
9	$11,778	90%	$10,600	$111	$198	$5,187	$16,096
10	$11,778	90%	$10,600	$111	$198	$5,187	$16,096
						NPV:	**$116,864**

II. Costs

Assumptions:

Charges:	**400**	per set
Batteries:	**$580**	per set
FTE Cost:	**$57,690**	per year
Elec price:	**$0.06**	per kwh
Elec use:	**0.2**	kwh/charge
Support:	**6%**	FTE
Discount:	**5%**	per year

Year	Machine	Batteries	Wheels	Electricity	Rack	Train/Reroute	Total
1	$6,743	$363	$0	$3	$525	$37,633	$45,267
2	$0	$363	$0	$3	$0	$133	$499
3	$0	$363	$190	$3	$0	$133	$689
4	$0	$363	$0	$3	$0	$133	$499
5	$0	$363	$190	$3	$0	$133	$689
6	$7,817	$363	$0	$3	$525	$133	$8,841
7	$0	$363	$0	$3	$0	$133	$499
8	$0	$363	$190	$3	$0	$133	$689
9	$0	$363	$0	$3	$0	$133	$499
10	$0	$363	$190	$3	$0	$133	$689
						NPV:	**$53,270**
						B:C Ratio:	**2.19**